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PLEISTOCENE STRATIGRAPHY AND
PALEONTOLOGY OF MEADE
COUNTY, KANSAS

BY

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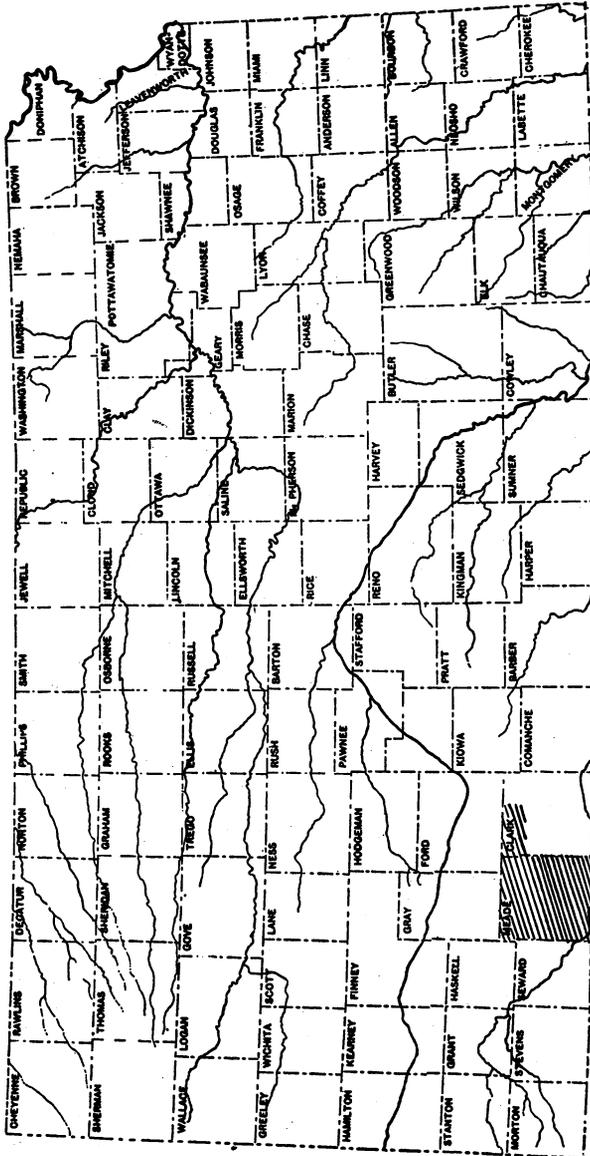
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INTRODUCTION

THE recognition of the relative age of successive Pleistocene faunas in Meade County, Kansas, and the surrounding region necessitates a revision of the geological sequence of the post-Pliocene deposits of the area. A brief history of the earlier investigations of these deposits and their vertebrate fossils gives the background for the stratigraphic discussion that follows.

In 1896 F. W. Cragin (pp. 51-54) described three lithologic units in southwestern Kansas which he considered to be "formations of the *Tule division* of Cummins (Equus beds of Cope), and to rep-



MAP. 1. Base map of Kansas. Crosshatched area covered in this report.

resent late Pliocene time." His original definition of these units and his designation of a locality where they are typically exposed was given as follows:

At several localities in Kansas, typically on Bluff Creek in Clark County, in the immediate vicinity of the old Vanhem post office (see Map 3), occurs a succession of three terranes: (1) the lowest, consisting of gravels and sands laid down in deep and broad valleys; (2) the middle, consisting of a wide-spread horizon of white to brownish (rarely greenish) volcanic ash; and (3) the highest, consisting of yellowish-brown lacustrine or slack-water marls, containing variously shaped concretions of carbonate of lime. They are conformable with each other and unconformably overlain with local beds of marl, sand, diatomaceous earth, etc., of supposed Quaternary age.

These were named by Cragin, (1) the Meade Gravels, (2) the Pearlette Ash, and (3) the Kingsdown Marls. He named the Meade Gravels after Meade Center (now Meade, Kansas), where "the gravels constitute the artesian water-holding formation." The volcanic ash was called the Pearlette Ash from the old post office of Pearlette, in Meade County (NW. $\frac{1}{4}$ sec. 27, T. 30 S., R. 27 W.), and the name Kingsdown Marls from the station of Kingsdown, west of Bucklin, Kansas, on the Rock Island Railroad. Cragin referred to the "Meade formation" in his report, thus indicating that he considered these units to be of formational rank. O. P. Hay (1917) described, in part, the collection of fossil vertebrates made by F. W. Cragin from this region.

In 1940 H. T. U. Smith assigned the Meade Gravels of Clark and Meade counties to the uppermost bed of the Rexroad formation, on the basis of horse remains identified by Hibbard as *Equus (Plesippus) simplicidens* Cope and *Nannippus phlegon* (Hay) and considered by Hibbard to be Upper Pliocene in age.

Frye and Hibbard (1941, p. 411) redefined the Meade formation to include: (1) the "Meade Gravels" of Cragin at the base (Smith's uppermost bed of the Rexroad formation); (2) Cragin's "Pearlette Ash"; (3) Smith's "Odee formation"; (4) the "*Equus niobrarensis* Beds"; (5) the "Jones Ranch Beds"; and (6) all other beds of Pleistocene age above the Rexroad member of the Ogallala formation and below the Kingsdown silt. They designated the type locality of the Meade formation as exposures along Crooked Creek Valley in Meade Center Township, south of the city of Meade, Kansas, and

particularly the Pleistocene beds exposed in sec. 21, T. 33 S., R. 28 W. (Map 2, locality 4). The assignment to the Meade formation of these various lithologic units, which had not been thoroughly studied at that time, was made to expedite mapping in the area.

The type locality of the Meade formation designated by Frye and Hibbard (1941) does not include the "Meade Gravels" as defined by Cragin. The sands and gravels occurring in the immediate vicinity of the old Vanhem post office (in the NW.¼ sec. 13, T. 30 S., R. 23 W., Clark County) are not equivalent to the sands and gravels occurring in the new type locality designated in 1941 by Frye and Hibbard for the Meade formation, on the east side of Crooked Creek in Meade County (in sec. 21, T. 33 S., R. 28 W.). The "basal sand and gravel" of the Meade formation referred to by Hibbard (1944) is equivalent to the sands and gravels exposed in the vicinity of the Vanhem post office.

Cragin definitely considered the sands and gravels occurring in Clark County as equivalent to the sands and gravels in Meade County. It may be, however, that he did not see the uppermost sands and gravels below the Pearlette Ash, since he stated that the Meade Gravels "constitute the artesian-water-holding formation" and that they "frequently contain hard ledges in Meade County and elsewhere." Only the lower sands and gravels (the basal Meade sand and gravel of Hibbard, 1944) are known to be extensively consolidated in Meade County.

MEADE FORMATION

The Meade formation is here redefined to include the original deposits designated by Cragin as the "Meade Gravels" in the area of the old Vanhem post office. It is also defined to include the overlying silts and caliche exposed in the section on a tributary of Spring Creek, west of Crooked Creek. These upper beds are not present near the Vanhem post office, but they occur below another gravel here included with the Pearlette Ash in the Crooked Creek formation. In the section near the Vanhem post office the Pearlette Ash is separated from the Meade Gravels by only a few inches of silt which belongs to the Crooked Creek formation. The name Crooked Creek formation is first used and defined in this paper.

Meade Gravels Member

The basal sands and gravels are here designated as the Meade Gravels member of the Meade formation, thus retaining the name and the type locality given by Cragin, in the vicinity of the old Vanhem post office. The type exposures are in Clark County (in sec. 12, T. 30 S., R. 23 W., and secs. 7 and 18, T. 30 S., R. 22 W.) on the north side of Bluff Creek. The Vanhem post office (in the NW.¼ sec. 13, T. 30 S., R. 23 W.) was just to the southwest of these exposures. One of the best outcrops of the Meade Gravels member is in Meade County, about fifty miles to the southwest, in sec. 9, T. 33 S., R. 29 W. (Hibbard, 1944, Pl. 3, Fig. 1, and Frye, 1942, Pl. 2, Fig. A.). The Meade Gravels have yielded the remains of *Equus* (*Hippotigris*) *simplicidens* Cope, *Nannippus phlegon* (Hay), *Stegomastodon mirificus* (Leidy), and camel.

Missler Member

The beds overlying the Meade Gravels and below the Crooked Creek formation are here named the Missler member of the Meade formation, for the town of Missler on the Rock Island Railroad (sec. 26, T. 31 S., R. 29 W.). The type locality of the Missler member is about 2½ miles southeast of Missler along a tributary of Spring Creek in Meade County, Kansas (secs. 6 and 7, T. 32 S., R. 28 W.).

The type locality of the Meade formation is here redesignated to conform with the new definition of the formation proposed in this paper. It includes exposures along a tributary of Spring Creek in SW.¼ sec. 6 and in sec. 7, T. 32 S., R. 28 W. Good exposures of the Meade formation occur along Stump Arroyo and its tributaries (in secs. 9, 15, and 22, T. 33 S., R. 29 W.), and along the breaks of the Cimarron River (Byrne and McLaughlin, 1948) in the southwest corner of Meade County and in the southeast corner of Seward County.

Section at the Type Locality of the Meade Formation

In the SW.¼ sec. 6, T. 32 S., R. 28 W., beginning on the south side of U. S. Highway 160, and extending along the east bank of the tributary, in sec. 7, T. 32 S., R. 28 W., Meade County, Kansas.

	<i>Thickness feet</i>
Top soil	
Crooked Creek formation	
9. Silt, sandy, reddish, grades upward into caliche	4.0
8. Silt, sandy, reddish	10.0
Stump Arroyo member	
7. Gravel to fine sand, reddish and light tan, with white quartz pebbles, rarely cemented	13.0
Unconformity	
Meade formation	
Missler member	
6. Silt, reddish, stained on surface with calcium carbonate grading upward into caliche	6.0
5. Silt, sandy, reddish (containing scattered gravel) mottled with caliche	11.0
Meade Gravels member	
4. Sand and gravel, dark, coarse at base, manganese stained, upper five feet fine to coarse sand, cross-bedded, partly cemented, containing some reworked Rexroad clay, grades upward into bed 5	12.0
Unconformity	
Rexroad formation	
3. Clay, blue gray to rust mottled	2.5
2. Caliche	0.25
1. Silt, sandy and micaceous, rusty buff to yellow rust	5.0

South and east of the measured section is a large gravel pit, along the floor of which can be seen the contact of the Rexroad formation and Meade Gravels member. In the walls of the pit the Missler silts are exposed, and on the upland, to the southeast, the Pearlette Ash overlies in some places the gray silt containing the Cudahy fauna and in others the sands and gravels of the Crooked Creek formation.

Deer Park Fauna

The following vertebrate fossils (Deer Park fauna) have been taken from the Missler member exposed above the Meade Gravels in the Meade County State Park (in the S.½ sec. 15, T. 33 S., R. 29 W., Kansas University, locality No. 1; see Map 2, locality 1).

MAMMALIA

Rodentia

Geomys sp.

Procastoroides lanei (Hibbard)

Pliolemmus antiquus Hibbard

Pliopotamys meadensis Hibbard

Proboscidea

Stegomastodon mirificus (Leidy)

Perissodactyla

Nannippus phlegon (Hay)*Equus (Hippotigris) simplicidens* Cope

Artiodactyla

Camelops sp.

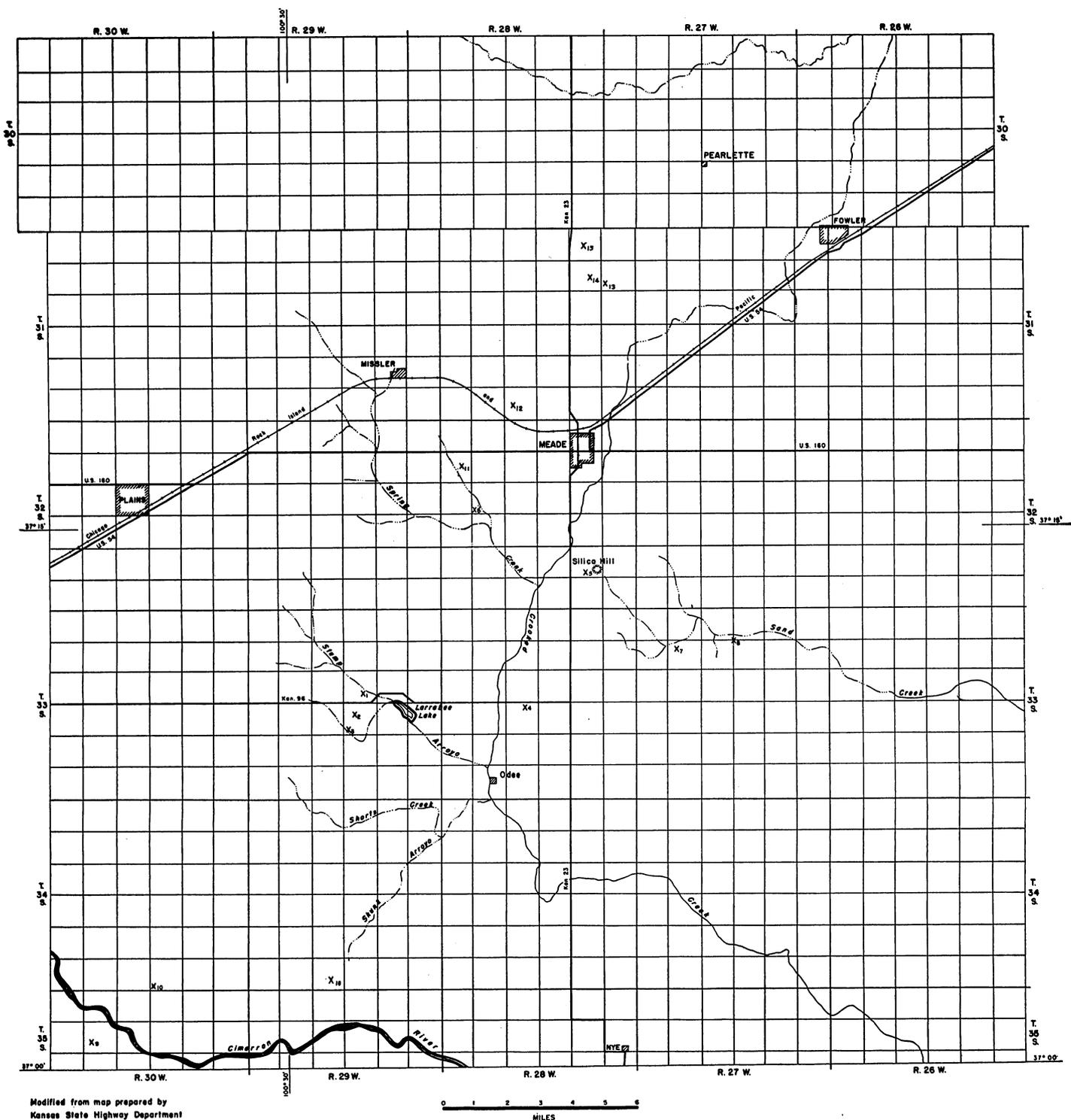
Hibbard (1937) included the beds containing these fossils in the Rexroad formation, but further field work has shown that the fossils were taken from the overlying Meade formation. They are not to be considered as a part of the Rexroad fauna, although some forms are common to both. The vertebrates taken from this deposit are here designated the Deer Park fauna and are considered to be of Lower Pleistocene age. It was on the basis of these forms that Hibbard postulated a cooler condition for that region than was indicated by forms in the Rexroad fauna from localities No. 2 and No. 3 (see Map 2).

CROOKED CREEK FORMATION

The name Crooked Creek formation (new name) is proposed for the sediments laid down during the cycle of deposition which followed the Meade formation, and includes the following succession of lithologic units from the base upward: (1) sands and gravels, (2) silt, (3) the Pearlette Ash, and (4) overlying deposits up to and including a well-developed caliche. The name is taken from a tributary of the Cimarron River which flows through Meade County, Kansas.

The type locality of the formation is in the S. $\frac{1}{2}$ sec. 16, W. $\frac{1}{2}$ sec. 15, and the N. $\frac{1}{2}$ sec. 21, T. 33 S., R. 28 W., on the east side of Crooked Creek, Meade County, Kansas. This is the same locality that was designated by Frye and Hibbard (1941) as the type of the Meade formation. It is now known that the beds to which Cragin (1896) applied the name Meade formation do not occur in this sequence of Pleistocene deposits but belong to an older series of Pleistocene beds. The volcanic ash occurs in a series of beds laid down during a cycle of deposition which followed extensive channeling of the older beds. This series underwent some erosion before a subsequent period of deposition in this region and it is considered best to apply a formational name to the beds belonging to each cycle

MEADE COUNTY KANSAS



MAP 2. Base map of Meade County, Kansas.

Localities: 1—Deer Park fauna. 2—Rexroad fauna. 3—Rexroad fauna. 4—Borchers fauna. 5—Cudahy fauna. 6—Cragin Quarry fauna. 7—Jones fauna. 8—Horse Quarry (Smith's "*Equus niobrarensis* Beds"). 9—Wolf Canyon. 10—Keefe Canyon. 11—Cudahy fauna. 12—Cudahy fauna. 13—Cudahy fauna. 14—Cudahy fauna. 15—Cudahy fauna. 16—Smith's locality B (XI Ranch).

of deposition, thus reducing Cragin's Pearlette Ash formation to that of a member of the Crooked Creek formation.

Section at the Type Locality of the Crooked Creek Formation

In the extreme NE.¼ sec. 20 and the N.½ sec. 21, T. 33 S., R. 28 W., on the east side of Crooked Creek, Meade County, Kansas, modified after Frye, 1942, p. 98.

	<i>Thickness feet</i>
Top Soil	
17. Silt, sand and some clay, tan to buff brown, massive. Contains sand and some caliche. The surface at the top of bluff is covered with a rubble of caliche	14.8
16. Silt, sandy, gray to tan	5.4
15. Clay, with some silt and sand, light gray, massive. Breaks with a conchoidal fracture when dry	4.5
14. Silt, clay, and some sand, gray massive, containing a few calcareous nodules (<i>Borchers fauna</i>)	6.4
13. <i>Pearlette Ash member</i> . Volcanic ash, pearl gray, lenticular, somewhat impure	7.1
12. Clay, silt, and some sand, tan gray and brown gray, massive. <i>Cudahy fauna</i> occurs in top 12 inches and base of ash	9.5
11. Sand, silt and coarse gravel, brown, contains abundant nodules. Grades upward into red-brown to reddish sandy silt	8.8
10. <i>Stump Arroyo member</i> . Sand coarse, reddish to light tan, and well sorted, containing white quartz pebbles, grading upward into finer more poorly sorted sand, calcareous nodules at top..	10.1
Unconformity	
Ogallala formation	
Total thickness of Ogallala formation	78.0
Permian (not exposed, known from test hole)	

After the type section was measured by Frye and Hibbard a highway was built through these exposures.

Stump Arroyo Member

Unit No. 10 of the type section of the Crooked Creek formation is here named the Stump Arroyo member of the Crooked Creek formation. The name is from a tributary of Crooked Creek which flows through Meade County State Park and empties into Crooked Creek in sec. 29, T. 33 S., R. 28 W. The type locality of the member is

in sec. 21, T. 33 S., R. 28 W. Gravels of the Stump Arroyo member form the high surface rubble in sec. 10, T. 33 S., R. 29 W., along a tributary of Stump Arroyo north of the Deer Park and west of the northwest corner of the Deer Park. The Deer Park is the west half of sec. 15, T. 33 S., R. 29 W. A good exposure of the Stump Arroyo member can be seen at the type locality of the Meade formation, just west of Meade, Kansas, along the south side of U. S. Highway 160, where it rests unconformably on the Missler member of the Meade formation. Here the Crooked Creek formation is not as extensively developed, and in some places the Pearlette Ash member rests directly on the Stump Arroyo member.

In sec. 20, T. 34 S., R. 30 W., the Stump Arroyo member is present, but poorly developed as a pebble zone overlain by a sandy red silt one to three feet thick. The geological section exposed at this locality is:

	<i>Thickness feet</i>
Crooked Creek formation	
7. Volcanic ash (Pearlette Ash member)	4.0
6. Silt sandy, reddish (varies from 1 to 3 feet) (Contains invertebrates)	3.0
5. Zone of pebbles	0.4
Unconformity	
4. Missler member. Silt, sandy, red with stringers of caliche	12.0
3. Meade Gravels member. Sands and gravels (basal 3 to 5 feet consolidated)	15.0
Unconformity	
Rexroad formation	
2. Clay, blue gray to brown (varies from 2 to 12 feet)	10.0
1. Silt, red, sandy (<i>Testudo riggsi</i>)..... (Base not exposed)	10.0

To the north and east of this locality, toward the upland surface, only the upper part of the Crooked Creek formation is exposed.

The Stump Arroyo member has not yielded fossils at any of the localities cited. This is in contrast to the fossiliferous character of the Meade Gravels with which it has been confused. Whether or not *Equus (Hippotigris) simplicidens* Cope and *Nannippus phlegon* (Hay), which are characteristic of the Meade Gravels, persisted as late in the Pleistocene as the Crooked Creek formation is not known.

That new horses appeared at this time is suggested by the occurrence of the remains of *Equus scotti* Gidley and *Equus calobatus* Troxell (cf. *Equus semiplicatus* Cope) in the silts and clays below the Pearlette Ash in sec. 21, T. 33 S., R. 32 W., Seward County, Kansas. *Equus scotti* Gidley has been taken from a gravel pit in the SE.¼ NE.¼ sec. 15, T. 18 S., R. 4 W., McPherson County, Kansas, from sands and gravels that are younger than the Meade Gravels, but older than the sands and gravels in the gravel pits in sec. 31, T. 18 S., R. 4 W., which yielded remains of *Equus niobrarensis* and *Mammothus columbi*. It may be that the sands and gravels in the SE.¼ NE.¼ sec. 15, T. 18 S., R. 4 W., are the same age as the lower part of the Crooked Creek formation.

Cudahy Fauna

The Cudahy fauna (Hibbard, 1944, p. 718) was collected from the top of the silts overlying the Stump Arroyo member and at the base of the Pearlette Ash in Meade County, Kansas. The same fauna was also found in Clark, Russell, and Lincoln counties, Kansas, in the same relationship to the Pearlette Ash. This gives some idea of the extent of the Crooked Creek formation, and especially of the Pearlette Ash member and the underlying silts.

The following mammals, associated with birds, amphibians, and gastropods, comprise the Cudahy fauna, which is widespread and occurs near the middle of the Crooked Creek formation (see Map 2, localities 5, 11-15).

MAMMALIA

Insectivora

- Sorex cinereus* Kerr
- Sorex cudahyensis* Hibbard
- Neosorex lacustrus* Hibbard
- Microsorex pratensis* Hibbard

Carnivora

- Mustela* sp.

Rodentia

- Citellus* sp.
- Parageomys tobinensis* Hibbard
- Reithrodontomys* cf. *pratincola* Hibbard
- Peromyscus cragini* Hibbard

Cudahyomys moorei Hibbard
Synaptomys (Mictomys) borealis (Richardson)
Microtus paroperarius Hibbard
Microtus (Pedomys) lanensis Hibbard
Pitymys meadensis Hibbard
Ondatra kansasensis Hibbard
 Perissodactyla
Equus sp.

The fauna seems to indicate the closing phase of a glacial age.

Notes on the Cudahy Fauna. During the summer of 1947 the University of Michigan Museum of Paleontology field party recovered a left ramus, No. 24511, of *Pitymys meadensis* Hibbard, bearing M_1 - M_3 . The specimen was taken from the silt below the Pearlette Ash in sec. 26, T. 32 S., R. 28 W., Meade County, Kansas, locality 17, locally known as "Silica Hill" (see Map 2, locality 5).

The holotype of *Pitymys meadensis*, a left ramus, Kansas University Museum of Vertebrate Paleontology, No. 6463, bearing M_1 - M_2 , was recovered from the same deposit and locality in the summer of 1942. Hibbard (1944, pp. 730-32) described the tooth pattern of the holotype and nine paratypes. Specimen U.M.M.P. No. 24511 possesses a slightly different tooth pattern for M_1 and M_2 than was observed in the above described series. That of M_1 of the specimen consists of a posterior loop, three alternating closed tri-



FIG. 2. Dentition pattern of *Pitymys meadensis* Hibbard. Left M_1 - M_3 , U.M.M.P. No. 24511. Occlusal view. $\times 10$. Drawing by Betty Brooks.

angles, the fourth and fifth triangles confluent and opening broadly into the anterior loop, which consists of the reduced sixth and seventh confluent alternating triangles and the rounded anterior loop. In the previously described pattern of M_1 the confluent fourth and fifth alternating triangles are closed where they join the sixth triangle, and do not open into the complex anterior loop.

Specimen No. 24511 is that of an adult with a well-worn dentition, which may account, in part, for the opening of the fourth and

fifth triangles into the sixth triangle. This is considered as a variable character which is known to occur in *Pitymys nemoralis* (Bailey), see Hibbard (1944, p. 732).

The tooth pattern for M_2 consists of a posterior loop, two alternating closed triangles, with the third and fourth alternating triangles confluent. In the holotype and paratypes the third and fourth alternating triangles of M_2 are closed. The open condition of the third and fourth triangles corresponds to the observations made on the M_2 in ninety-five lower jaws of Recent specimens of *Pitymys nemoralis* in the University of Kansas Museum of Natural History. Hinton (1926, p. 127) found this character to be variable in *Pitymys arvaloides* Hinton from the Pleistocene upper fresh-water bed at West Runton.

The pattern for M_3 of No. 24511 consists of a posterior loop, first and second alternating triangles which are broadly confluent and closed anteriorly, and the anterior loop (see Fig. 2).

The specimen agrees in other respects with the holotype. The anteroposterior diameter of the crowns of M_1 - M_2 of the holotype is 4.4 mm.

Measurements of specimen No. 24511, in millimeters, are as follows: alveolar length of M_1 - M_3 , 6.1; occlusal length of M_1 - M_3 , 5.65; occlusal length of M_1 - M_2 , 4.4; transverse width of the posterior loop of M_1 , 1.0; of M_2 , 0.85; of M_3 , 0.7; vertical height of M_2 , taken on the posterior loop, 3.2; of M_3 , on the posterior loop, 2.75; depth of ramus taken on inside below anterior loop of M_2 , 3.5.

Borchers Fauna

The Borchers fauna of interglacial age (Hibbard, 1941, 1942, and 1943) was recovered from the silts and clays above the Pearlette Ash at the type locality of the Crooked Creek formation (see Map 2, locality 4). It has never been recognized at any other locality. This is probably due to the great amount of erosion after the deposition of the Crooked Creek formation (see unit No. 14, page 71).

The fauna indicates a change in climatic conditions in Meade County after the time the Cudahy fauna lived. On the basis of the study of the Pearlette Ash and the Cudahy fauna, by Frye, Swine-

ford, and Leonard (1947) it appears that the Cudahy fauna consisted of forms that lived at the closing phase of the Kansan glacial age and that the Borchers interglacial fauna is Yarmouth in age.

The Borchers fauna contains the following vertebrates:

AMPHIBIA

Amphibian remains

REPTILIA

Testudo sp. (large)

AVES

Numerous bird remains

MAMMALIA

Insectivora

Sorex taylori Hibbard

Carnivora

Canis sp.

Mustela sp.

Spilogale cf. *leucoparia* Merriam

Felis sp.

Rodentia

Citellus meadensis Hibbard

Citellus cragini Hibbard

Geomys sp.

Perognathus gidleyi Hibbard

Perognathus pearlettensis Hibbard

Etadonomys tiheni Hibbard

Onychomys fossilis Hibbard

Reithrodontomys pratincola Hibbard

Parahodomys sp.

Sigmodon hilli Hibbard

Ondatra sp.

Synaptomys cf. *vetus* Wilson

Zapus burti Hibbard

Lagomorpha

Nekrolagus sp.

Hypolagus sp.

Lepus cf. *californicus* Gray

Perissodactyla

Equus sp.

Artiodactyla

Camelops sp.

Antilocapridae (sp.)

At the type locality of the Crooked Creek formation the caliche occasionally reaches a thickness of three feet. This resistant bed in

places forms the High Plains surface of the region. A study of the Crooked Creek formation in this area reveals that the present drainage of the Cimarron River and its tributaries, including Crooked Creek, and the terraces along them, were developed after the Crooked Creek formation had been laid down by streams of an earlier drainage system.

LATER PLEISTOCENE DEPOSITS

Most of the Pleistocene deposits younger than the Crooked Creek formation are found at lower topographic levels. Interpretation of their relationships is complicated by the fact that older Pleistocene strata have been channeled and younger beds deposited along the sides.

The development of extensive sink holes, some coalescing into topographic basins, in Meade and Seward counties, Kansas, and Beaver County, Oklahoma, throughout the Pleistocene, and their filling with sediments further complicates the study of stratigraphy and faunas in this area. Many of the older basins have been dissected by the Cimarron River and its tributaries. Each sink or basin presents a problem in itself since this dissection has exposed many feet of locally derived Pleistocene strata.

ODEE FORMATION

The Odee formation described by Smith (1940, pp. 100-108) in Meade County, Kansas, consists of beds which are chiefly or entirely younger than the Crooked Creek formation. It was "named for typical outcrops in Odee township, in southern Meade County." Regarding its distribution Smith stated that "north of the Cimarron Valley, the Odee is probably widespread, but is mostly covered, and is represented by fewer and smaller exposures. Of these the best that I found are those along Shorts Creek, in sec. 36, T. 33 S., R. 29 W., Meade County, and in the adjoining part of the section to the east." Because of the poor exposures he gave no measurement of the strata in Odee Township.

Pleistocene strata along Shorts Creek (locally known as "Lone Tree Arroyo") originated in two ways, first as sink-hole filling, and

second as stream deposits. The sink-hole filling was probably derived chiefly from Permian rocks in the walls of the sinks or near their rims. Some of the material is red clay and silt containing selenite crystals; some of it is blue to bluish-gray clay and silt containing gastropods. The sinks were chiefly developed along the Crooked Creek fault and are genetically related to it (Frye and Schoff, 1942).

The Pleistocene stream deposits along the lower part of Shorts Creek were laid down during an earlier time in the physiographic development of Meade County. At the present time Crooked Creek and its tributary Shorts Creek flow south and southeastward into the Cimarron Valley, but in late Pleistocene time Crooked Creek flowed southwestward across a part of what is now the valley of Shorts Creek in the approximate position of Skunk Arroyo (Skunky, a tributary of Shorts Creek) directly into the Cimarron River. As a result of sink-hole development and stream piracy Crooked Creek was captured near the present junction of Shorts Creek by a stream which flowed southeastward into the Cimarron at the approximate position of the present valley occupied by the lower part of Crooked Creek. Owing to stream piracy the drainage of Skunk Arroyo was reversed from the earlier drainage of Crooked Creek. Skunk Arroyo now flows northeastward into Shorts Creek. The fossiliferous Pleistocene stream deposits exposed in sec. 36, T. 33 S., R. 29 W., were laid down by this ancestral Crooked Creek before its course was diverted to the southeast. From Shorts Creek and Skunk Arroyo the broad valley cut by the ancestral Crooked Creek and accentuated by further subsidence can be plainly seen at the present time trending in a southwesterly direction into the Cimarron Valley. The present drainage of Crooked Creek cuts through the east side of this ancestral valley.

It is evident from Smith's discussion that he considered the red sink-hole deposits as the most typical of the Odee formation. The type locality of the Odee formation is here designated as exposures in sec. 35, T. 34 S., R. 29 W., Cimarron Township, Meade County, where Smith measured a fossiliferous section (1940, p. 101). His bed No. 4 has yielded abundant ostracods and gastropods. Bed No. 5 yielded poorly preserved vertebrate fragments. The only identifiable vertebrate taken from this exposure was part of the skull of *Citellus*

richardsonii (Sabine) from Smith's bed No. 6, which indicates that the deposits are of late Pleistocene age.

Two miles west of the designated type locality of the Odee formation is Smith's locality B, which consists of approximately forty-five feet of exposed beds assigned by him to the Odee formation. The following vertebrates have been taken from these exposures: *Capromeryx furcifer* Matthew was taken by Francis Cochran from Smith's bed No. 1 (1940, p. 102); *Microtus pennsylvanicus* (Ord) was recovered from bed No. 3 or No. 4 (Hibbard, 1943); and *Aenocyon dirus* (Leidy), *Equus*, and *Camelops* have been taken from bed No. 4 (see Map 2, locality 16). The seventy-five to one hundred feet of sands and gravels reported by Smith as underlying these deposits are considered to be the "High Terrace" deposits which have been greatly distorted due to the development of a sink or series of sinks in that area.

Cragin (1896, p. 54) discussed the age of part of the beds here included in the Odee formation. He considered the Meade Gravels, Pearlette Ash, and the Kingsdown Marls as "supposedly late Pliocene," and stated that they are "unconformably overlaid with local beds of marl, sand, diatomaceous earth, etc., of supposed Quaternary age." He definitely recognized, therefore, much younger beds in the region than the three formations he described. In the upper part of the section (bed 15) measured by Smith (1940, p. 103) in the Nye Sink in sec. 15, T. 6 N., R. 25 E.C.M., Beaver County, Oklahoma, diatomaceous earth is present.

Directly beneath the diatomaceous earth, from the silt and clay, were recovered the remains of *Synaptomys bunkeri* Hibbard (1939a) and *Mammuthus columbi* (Falconer), both of which indicate that the beds are of late Pleistocene age.

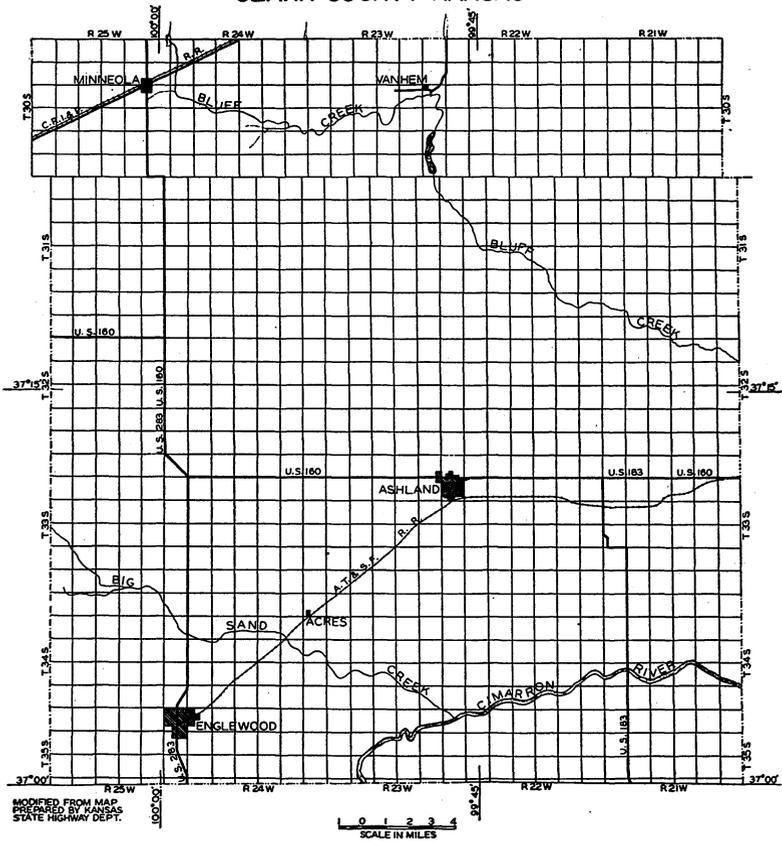
Another local deposit of diatomaceous earth is present at Smith's locality B, which is down stream from and at a higher horizon than the locality where the large wolf (*Aenocyon dirus*) was taken.

It seems best to restrict the Odee formation to the scattered deposits of basin filling of local origin. The study of the vertebrate fossils recovered from these deposits indicates that the age of these deposits is post-Crooked Creek.

KINGSDOWN FORMATION

The Kingsdown Marls formation was described by Cragin in 1896. Smith (1940, p. 111) included Cragin's "Kingsdown Marls" and the overlying beds, with the exception of the overlying loess, in

CLARK COUNTY KANSAS



MAP. 3. Base map of Clark County, Kansas.

the Kingsdown formation. Frye and Hibbard (1941, p. 419) used the term "Kingsdown Silt" to include both the beds designated by Smith and the overlying loess, since it was impossible in some places

to determine with certainty whether some of the upper beds were aeolian or water-laid. Hibbard (1944, p. 746) restricted the beds described by Cragin as the Kingsdown Marls to the Lower Kingsdown Silt and the overlying beds were assigned to the Upper Kingsdown Silt.

Since 1941 the term Kingsdown Silt formation has been used constantly for the late Pleistocene deposits which consist chiefly of loess or of beds considered by Cragin to overlie unconformably the Kingsdown Marls formation. Only a few deposits occurring outside of Clark County, Kansas, to which the name Kingsdown formation or Kingsdown Silt formation has been assigned, contain beds designated by Cragin (1896) as the Kingsdown Marls formation. Beds equivalent in age to Cragin's Kingsdown Marls formation in Meade County, Kansas, have previously been included in the Meade formation.

The Kingsdown Marls formation of Cragin should be restricted to the older beds and considered to be a distinct formation for the following reasons: (1) the older beds are distinct lithologically and faunally from the younger overlying beds; (2) in the type area in Clark County, Kansas, they are a mappable unit; (3) the beds were deposited under different physiographic conditions than the younger unconformable overlying beds; (4) the areal extent of deposits of the two formations are not the same; (5) the two formations were laid down under two distinct erosional and depositional cycles; and (6) the younger deposits were excluded by definition by Cragin at the time of the naming of the Kingsdown Marls formation.

The Kingsdown formation is here redefined to include the sands and gravels at the base of the silt not recognized by Cragin but included by Hibbard (1944) in the "Lower Kingsdown Silt." The term Kingsdown formation is here used instead of Cragin's Kingsdown Marls since the unit here defined as a formation consists both of channel sands and gravels and flood-plain silts containing a large amount of calcium carbonate. The color of the Kingsdown Silts in Clark County seems to reflect greatly the contained reworked ash from the Pearlette Ash member of the Crooked Creek formation. The use of the Kingsdown formation as here restricted and redefined

is not the use of the term as defined by Smith (1940). The typical section given by Smith (1940, p. 112) for the Kingsdown formation in sec. 13, T. 30 S., R. 23 W., is of beds younger than those described by Cragin as the Kingsdown Marls and belong to a later cycle of erosion and deposition named and defined in this paper as the Vanhem formation.

The type locality of the Kingsdown formation is along the north side of the upper part of Bluff Creek, Clark County. The beds are well exposed in secs. 8, 17, 10, 11, 12, and 13, T. 30 S., R. 23 W. The type section of the formation is assigned to exposures north of the George Taylor ranch house exposed in the walls of the north-south gulch produced by a tributary of Bluff Creek in secs. 8 and 17, T. 30 S., R. 23 W.

Typical section of the Kingsdown formation after Hibbard (1944, p. 746). In SE.¼, sec. 17, T. 30 S., R. 23 W., Clark County.

	<i>Thickness feet</i>
Vanhem formation	
4. Silt, light tan, grading upward into top soil	5.0
Unconformity	
Kingsdown formation	
3. Silt, thick-bedded, light buff, grading into sandy silt and fine sand at base, contains some gastropods	20.0
2. Gravel, composed of abraded caliche, thin-bedded and cross-bedded, containing igneous rock types, at top a thin lenticular caliche bed	5.0
Unconformity	
Meade formation	
1. Sand, medium to coarse, mortar bed near top, 6 to 12 inches thick, tightly cemented fine sand, pink granite and pebbles. Base covered	15.0

Typical section of Kingsdown formation after Hibbard (1944, p. 747). In sec. 8, T. 30 S., R. 23 W., Clark County.

	<i>Thickness feet</i>
Kingsdown formation	
4. Silt, light buff, containing a few scattered concretions and fragments of fossil turtle, grades upward into top soil	25.0

- 3. Reworked Pearlette Ash, interbedded with and reworked into the light buff silt 10.8

Disconformity

Crooked Creek formation

- 2. Pearlette Ash member. Ash, cross-bedded, weathers to form a resistant bench on north exposures, where moist, covered with moss, beds dipping toward the southeast 10.0
- 1. Silt, sandy, reddish, in places it grades downward into a sandy silt, light tan, containing pockets of fine sand. Base not exposed 16.5

The variously shaped concretions of carbonate and silicate of lime mentioned by Cragin occur in exposures in secs. 11, 12, T. 30 S., R. 23 W.

All studies to date in Meade County indicate that stream deposits of post-Crooked Creek and pre-Vanhem age are equivalent to the Kingsdown formation of Clark County, Kansas. In sec. 33, T. 34 S., R. 29 W., Meade County, Kansas, the sands that underlie the strata of the Odee formation measured by Smith (1940, p. 102) are considered as High Terrace sands and gravels that were laid down during the early development of the Cimarron Valley (see Hibbard, 1943, p. 190). Remains of specimens of *Ambystoma*, *Emys twentiei* Taylor, *Geomys*, *Mammuthus columbi*, *Equus*, and *Camelops* taken from these sands and gravels appear to be contemporaneous with the Cragin Quarry fauna collected in the SW $\frac{1}{4}$ sec. 17, T. 32 S., R. 28 W., Big Springs Ranch, Meade County, Kansas. Cragin worked this quarry in 1891; Hibbard and his party worked here in 1937 and 1945. The deposit was formed in the basin of an old artesian spring. Owing to the down-cutting of Crooked Creek and Spring Creek the spring shifted and is probably the same one that now flows at nearly stream level, approximately fifty feet lower than the quarry, and is located a few yards northeast along the south bank of a tributary of Spring Creek. These deposits are probably equivalent, in part, to the Kingsdown formation (Hibbard, 1944, pp. 746-49).

Cragin Quarry Fauna

The Cragin Quarry fauna at the original locality contains the following mammals (Hibbard, 1939), see Map 2, locality 6:

MAMMALIA

Carnivora

- Aenocyon dirus* (Leidy)
- Smilodon* sp.
- Panthera atrox* (Leidy)
- Felis* cf. *oregonensis* Rafinesque

Rodentia

- Geomys* sp.

Lagomorpha

- Lepus* sp.

Proboscidea

- Mammuthus columbi* (Falconer)

Edentata

- Paramylodon harlani* (Owen)

Perissodactyla

- Equus francisci* Hay
- Equus niobrarensis* Hay

Artiodactyla

- Camelops kansanus* Leidy
- Tanupolama* sp.
- Breameryx minimus* (Meade)

Smith's "*Equus niobrarensis* beds" (1940, pp. 109-10) in a road cut on the south side of Sand Creek (secs. 9 and 10, T. 33 S., R. 27 W.) are younger than the Crooked Creek formation and older than the Upper Kingsdown formation (see Map 2, locality 8). They appear to be equivalent to a part of the Kingsdown formation. These beds are of local sink-hole origin and related to the Jones Basin complex. The overlying beds which are equivalent in part to the Vanhem formation contain invertebrates and vertebrates identical with the Jones fauna (Hibbard, 1940) which was taken one and one-half miles to the southwest.

VANHEM FORMATION

The name Vanhem formation (new name) is proposed for sediments laid down during a cycle of deposition which followed the entrenchment of streams into the Kingsdown and older formations. The Vanhem formation includes the following succession of lithologic units from the base upward: (1) sand and gravel, (2) silt, (3) silt to clayey silt, and (4) loess. The name is taken from the Vanhem post office, which was located in the N.½ of sec. 13, T. 30 S., R. 23 W., Clark County, Kansas.

The type locality of the Vanhem formation is in the N.½ of sec. 13 and the S.½ sec. 12, of T. 30 S., R. 23 W., Pyle Ranch (Stephenson Ranch) on the north side of Bluff Creek, Clark County, Kansas.

The type section of the Vanhem formation is located along the west bluff of a small tributary of Bluff Creek in secs. 13 and 12, T. 30 S., R. 23 W. The section is that given by Smith (1940) as a typical section of the Kingsdown formation.

Type section of the Vanhem formation modified after Smith (1940, p. 112). In sec. 13, T. 30 S., R. 23 W., Clark County, Kansas.

	<i>Thickness feet</i>
Vanhem formation	
4. Silt, light tan, even-bedded to finely laminated below, grading upward into structureless, loesslike silt and loess at top....	50.0
3. Sand, silty, gray, containing small pebbly bands below, grading into structureless calcareous silt above; abundant invertebrates	16.0
2. Sand and gravel, rusty to sooty black, abundant calcareous pebbles and fragmentary slabs of mortar-bed conglomerate, obviously reworked; contact indistinct	2.0
Meade formation	
Meade Gravels	
1. Sand and gravel, well-cemented toward the top (containing remains of <i>Equus simplicidens</i> , <i>Nannippus phlegon</i> , and <i>Stegomastodon mirificus</i>)	26.0
Base not exposed, though Cretaceous rocks outcrop at stream level.	

The beds of the Vanhem formation in this section were excluded by Cragin (1896) at the time of the description of the Meade Gravels, Pearlette Ash, and Kingsdown Marls formations. Cragin considered these three formations as conformable with each other. The only place a conformity of the units exists is in the region of the Vanhem post office along the north tributaries of Bluff Creek. Smith (1940, p. 112) considered that the Pearlette Ash was related to the overlying silts in this area. Cragin said: "They are conformable with each other (the above units), and are unconformably overlaid with local beds of marl, sand, diatomaceous earth, etc., of supposed Quaternary age."

Westward from the top of the measured section of the Vanhem

formation but a few yards, beyond a flat divide covered by grama and buffalo grass, there is a drop over a small bluff consisting of Kingsdown formation. At this place the two exposures seem to be continuous, and only a change in facies accounts for the difference in lithology and color of the two exposed silts; actually the Vanhem formation is channeled into the Kingsdown formation and the contact between the two is completely hidden by slump and vegetation. A careful study of the two exposures upstream of either tributary reveals their true relationship.

Unfortunately, most of the exposures previously referred to or mapped as Kingsdown Silt are of younger deposits than the Kingsdown formation and are a part of the Vanhem formation.

The Vanhem formation is widespread in Meade County, where it chiefly mantles the upland surface. It is also present as the uppermost bed in many of the filled basins. One of the better exposures occurs at the top of a bluff on the Jones Ranch in sec. 8, T. 33 S., R. 27 W. At this locality the Jones fauna was taken sixteen feet below the highest point of the bluff (see Map 2, locality 7).

Jones Fauna

The Jones fauna (Hibbard, 1940, 1942, and 1943) is characteristic of the mammals taken from other exposures of the Vanhem formation. The following mammals were found associated with the remains of mollusks (Goodrich, 1940), fishes, amphibians (Tihen, 1942), and birds:

MAMMALIA

Insectivora

Sorex cinereus Kerr

Carnivora

Mephitis mesomelas Lichtenstein

Taxidea taxus (Schreber)

Rodentia

Citellus richardsonii (Sabine)

Citellus tridecemlineatus (Mitchill)

Cynomys ludovicianus (Ord)

Geomys sp.

Perognathus sp.

Onychomys leucogaster (Wied)

Peromyscus sp.

Microtus (Pedomys) ochrogaster (Wagner)

Microtus pennsylvanicus (Ord)

Artiodactyla

Camelops sp. (taken 1947)

Platygonus sp.

SUMMARY OF THE PLEISTOCENE STRATIGRAPHY OF SOUTHWESTERN KANSAS

The oldest Pleistocene deposits in southwestern Kansas comprise the Meade formation. During this cycle of deposition the streams were rejuvenated and cut deeply into underlying beds, depositing coarse sands and gravels in their channels. The carrying power of the streams then decreased, possibly due to the development of a local base level. The sands became fine and the stream valleys were filled or nearly filled with fine sandy silt. Beneath this surface a zone of massive caliche developed which probably indicates a period of semi-arid conditions. Later more silts were deposited showing a slight increase in their sand content indicating an increase in rainfall and runoff.

The Crooked Creek formation reflects another cycle of erosion and deposition. The streams again entrenched their courses and deposited channel and flood-plain sediments. The sequence of events that had occurred in the Meade time interval seems to have been largely repeated. In the upper part of this cycle there was a wide-spread ash fall resulting from volcanic activity in other areas which produced the Pearlette Ash.

The streams at the close of Crooked Creek time were flowing at a level that is now in part that of the High Plains surface of this region. Although the streams which deposited the Crooked Creek formation channeled the earlier deposits of the Meade formation, it seems probable from their relations that the streams of both cycles may have attained very nearly the same level at the close of the time interval represented by their deposits.

The present streams in Meade County and their terrace systems have been developed since the deposition of the Crooked Creek formation.

The Odee formation is restricted to sink-hole and basin fillings.

The Kingsdown Silt formation is redefined and divided to conform as nearly as possible to the original use of Cragin's "Kingsdown Marl" and still be in keeping with the other Pleistocene formations recognized in the region. The Kingsdown formation includes the silts assigned by Cragin to the formation and the channel phase related to them.

The younger overlying sands, gravels, silt, and loess are restricted from the Kingsdown formation and are given the name Vanhem formation.

Five successive Pleistocene faunas are known to occur in the Pleistocene deposits of Meade County. The oldest, the Deer Park fauna, is taken near the base of the Meade formation. The Cudahy fauna occurs at the base of the Pearlette Ash and at the top of the underlying silt, while the Borchers fauna occurs in the clayey silt just above the Pearlette Ash. These two faunas occur in the Crooked Creek formation. The Cragin Quarry fauna is considered as having been taken from deposits equivalent to the Kingsdown formation. The Jones fauna, a very late Pleistocene assemblage, occurs in the Vanhem formation.

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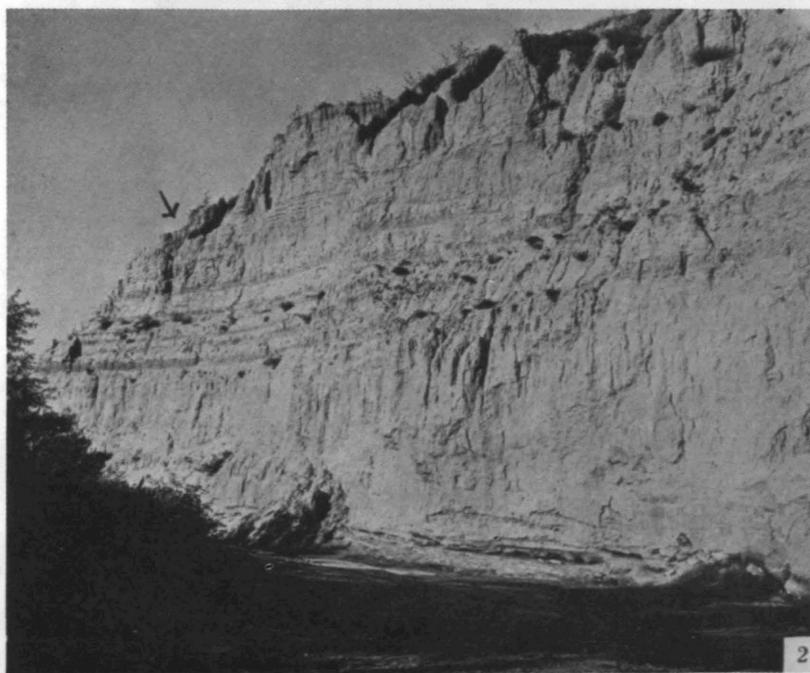
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EXPLANATION OF PLATE 1

- FIG. 1. Borchers Quarry. The man is standing by the quarry and above the white resistant bench (Pearlette Ash) in the Crooked Creek formation. Borchers Ranch, Meade County, Kansas (see Map 2, locality 4).
- FIG. 2. Jones Quarry. The quarry is indicated by the arrow in the upper left-hand corner of the photograph. The Pleistocene deposits, cut by a tributary of Sand Creek, have a vertical height of 61 feet. The Jones fauna occurs 16 feet below the top of the exposure. Jones Ranch, Meade County, Kansas

PLATE I



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